

Coal Storage and Proportioning

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Summary

Intermediate storage of raw coal and pulverized coal is common practice with nowadays indirect coal preparation systems. As constant feed from such bins either to the coal mill or the burners of a kiln system is a prerequisite for a safe operation the problems related to coal handling and feed rate control will be discussed. For both coal qualities, wet raw coal and dry pulverized coal, criteria for bin design and feeder selection will be given.

1. INTRODUCTION

Intermediate storage of raw coal and pulverized coal is common practice with nowadays indirect coal preparation systems. Constant feed from these bins to the mill and to the burners of the kiln system is a prerequisite for a safe operation. Any interruption in coal supply heightens the risk of explosions inside the mill or inside the precipitators. During start-up of many of the modern coal preparation plants marked discharge problems were encountered - either the bin outlet was crossed by a stable material bridge, or a rathole formed in the bin, or the feeder was flushed by aerated pulverized coal. In most cases such handling problems are directly attributable to an incorrect design of the bin outlets.

In this presentation raw coal and pulverized coal handling shall be discussed, above all the design of storage and feed bins, feeder selection and the problems related to feed rate control.

2. IMPACTS OF BULK MATERIAL FLOWABILITY ON BIN DESIGN AND FEEDER SELECTION

As to create a common base for further discussions, first of all some terms should be cleared up.

- ◆ Both, coarse, wet raw coal and dry pulverized coal - as different their properties are - show a typical cohesive behavior. Cohesive means, that the interparticle forces result in strength, being the reason for the ability of coal to form and support stable obstructions to flow as arches or ratholes.
- ◆ As utmost availability and reliability of operation are the fundamental requirements to meet by modern coal preparation plants, it is evident that all storage and feed bins for raw coal as well as for pulverized coal must be designed for mass-flow. By the way, mass-flow means that all the material contained in a bin is activated and moves to the bin outlet, whenever any of it is discharged. This in contrast to funnel-flow where material in a narrow core only just above the discharge opening is activated.

3. RAW COAL HANDLING DESIGN OF MILL FEED BINS AND FEEDER SELECTION

As already mentioned, wet raw coal is a bulk material of considerable cohesiveness. The major risks in coal mill operation are interruptions in coal supply. As to guarantee highest reliability of operation, coal mill feed bins must be designed for mass-flow.

3.1 General Comment on Mill Feed Bin Design

Some comments seem to be opportune:

Do not abuse coal feed bins as additional storage bins. With regard to possible discharge problems they should be designed for capacities as low as possible or even be avoided following the rule that "the best bin is no bin" (figure 1). In case the feed bin is fed from a fully automatic storage pile, a bin capacity of one to three hours of continuous mill operation is sufficient. In case several feed bins - one bin for each coal quality which should be mixed - are fed discontinuously by front end loaders, higher bin capacities, sufficient for one to three shifts of continuous mill operation, are required.

- ◆ Never use one bin to feed several mills. As simultaneous operation of the mills cannot be maintained all the time and discharge problems are therefore programmed during a shut-down of one mill.
- ◆ Wedge shaped bin discharge hoppers with slotted openings are preferred to conical bin discharge hoppers with circular openings as they can be equipped with smaller feeders.
Note: The minimum width of a slotted opening required to prevent arching is half the diameter required for a circular outlet. A slot, by the way, is defined to be a rectangular opening with a length which is at least two and a half times its width.
- ◆ From table 3 it becomes evident that all the wall slopes of mass-flow bin discharge hoppers strongly depend on the material of which the hopper is made or by which it is lined. Obviously the general statement that hopper walls should not be inclined less than 70 degree is not sufficient. This statement is only valid for Ultra High Molecular Weight (UHMW) Polyethylene (PE).
Hence it follows that new coal feed bins should be designed with PE lined wedge shaped discharge hoppers, and that, by a PE-lining, feed bins with a funnel-flow sequence can be in some cases converted to mass-flow.
- ◆ When selecting a feeder system it should be kept in mind that bin, interface to the feeder and feeder work as one system. Any change in one will affect the performance of the whole system.
What selection of feeder size concerns, there is a primateship of the requirements for discharge reliability over all other requirements, i.e. that sometimes, based on material's flow properties, a wider feeder must be selected than required when considering the feed rate as exclusive design criteria.
The design of the interface is of particular importance with regard to the flow pattern that will develop in a bin. Mass-flow will develop provided that the interface is designed such that the entire bin discharge opening is activated whenever material is withdrawn. In case of raw coal this is problematic. On one hand, raw coal requires wide discharge openings due to its cohesion. On the other hand, the required feed rates are low. Together with most feeder's tendency to discharge preferably from the rear, this result in an only partly active outlet (figure 2). To remedy this problem the interface must be designed expanding, i.e. such that the volume of the material bed on the feeder increases in direction of material flow. This in turn initiate material flow not only at the rear but across the full discharge opening (figure 2).

3.2 Comment on Feeder Selection

Volumetric feeders are sufficient for feed rate control to the coal mill. The possibility of gravimetric feed rate control which offer some feeders is not a sufficient criterion to select a more expensive or more complicated feed system.

The belt conveyor is quite common for the discharge of tipping hoppers. There is no reason which would exclude its application as feeder underneath a raw coal bin. As belt conveyors are not gas tight, an additional device must be installed to provide for the air lock to the mill. Gravimetric feed rate control is possible if the belt conveyor is designed as weigh feeder. With regard to an expanding outlet, the feeder width should be selected to be twice the width of the bin discharge opening (figure 4).

The apron feeder proved to be a very reliable but expensive feeder. Its application is justified at least with very large raw coal storage bins. As to an expanding outlet design, similar criteria apply as for weigh feeders.

The casing of a trough chain conveyor is completely air and dust tight. With such feeders there is no problem with spillage. A sufficient air lock to the mill is achieved if a minimum material height of 3 m is maintained in the feed bin. Trough chain conveyors show a strong tendency to discharge material preferably from the rear. The most advanced feeder Redler - one of several suppliers of such feeders - supplies for raw coal applications is equipped with an expanding interface (figure 5) and a nucleonic scale as to provide gravimetric feed rate control.

Trough chain conveyors are judged to be very reliable but expensive feeders.

The table feeder is quite common for raw coal applications. With the feed bin arranged just above the mill inlet a very compact plant design can be reached. Table feeders allow a volumetric feed rate control. Such a feeder is usually a quite large equipment as it is applied with conical bin discharge hoppers - remember, the minimum diameter of a circular discharge opening required to prevent arching is twice the width of a slotted discharge opening. With regard to a fully active outlet the side skirts at the end of the feed-in line should have a 'corkscrew' shape (figure 6).

The un-coaler feeder (figure 7) is quite a new development. Its mode of operation is similar to that of a bin activator, but its design is much more rigid. A center dome functions as activator or live bottom when vibrated. By this, material flow becomes unproblematic. Furthermore such a feeder can be fitted directly to the bin discharge opening without any need for an expanding interface. Automated control systems arranged to respond to belt scale signals allow volumetric feed rate control.

The un-coaler feeder is considered to be a very reliable feeder for raw coal.

3.3 How would a Mill Feed Bin for Raw Coal look like, when Designed for Reliable Operation?

(figure 3)

- ◆ The bin would definitely be designed for mass-flow.
- ◆ The front wall of its wedge shaped discharge hopper would be by about 5 degree steeper than its rear wall.
- ◆ The slotted bin discharge opening would rather be trapezoidal than rectangular, with a minimum width of 800 mm and a taper of about 2 - 3 degrees.
- ◆ Guide plates would be fitted to the pin gate, corresponding to the shape of the bin discharge opening.
- ◆ The interface would be expanding in direction of material flow.
- ◆ A feeder of at least 1600 mm in width would be selected.

**4. PULVERIZED COAL HANDLING
DESIGN OF STORAGE BINS AND FEED RATE CONTROL**

With pulverized coal, handling problems are similar to that with raw coal, although the mechanical properties of these two coal qualities are quite different. As raw coal to the mill, pulverized coal must be fed at a controlled rate to the burner as to guarantee complete combustion. Prerequisite for an accurate feed rate control is again reliable material discharge from the storage bin. And again, mass-flow would be the most suitable flow sequence in a pulverized coal storage bin.

4.1 Standard Design Criteria for Pulverized Coal Handling Systems

Nowadays, storage bins of a standard design are offered for pulverized coal by specialized suppliers. Such bins are pressure shock resistant and fully equipped with feeding and flow rate control systems, with the necessary monitoring equipment like load cells for bin content control, temperature and CO measuring devices, with safety equipment as explosion doors and inertization systems. Suppliers design bin discharge hoppers with a standard slope of not less than 70 degree and made of stainless steel. To prevent caking due to condensation effects the discharge hoppers are provided with a thermal insulation.

Modern pulverized coal feeders are of a gravimetric type and have proved successful in supplying the fuel at a controlled rate to the burner.

4.2 Discharge Problems with Pulverized Coal

Most discharge problems from pulverized coal bins are due to a deficient design of the bin outlet section.

To overcome bridging and ratholing discharge aids have been installed either of a mechanical type such as paddle wheels or of a pneumatic type such as pulsed air nozzles.

But still, for some solutions, pulverized coal's flow properties have been ignored. A typical example: For a bin discharge design (figure 8) where the bin's discharge hopper penetrates a rectangular cube, discharge problems are immanent for a cube width smaller than 600 mm, even if a paddle wheel is installed. A sledge hammer, an old fashioned device, often proved to be the most suitable discharge aid.

Note: The sections which must be activated to prevent arching of pulverized coal are at least 1200 mm in diameter for circular discharge openings or at least 600 mm in width for slotted discharge openings.

In operational practice it also became manifest that the standard hopper slope of 70 degree even with stainless steel is not sufficient in all cases. As a result ratholes have formed in the bins. Again, aeration systems were installed as to promote material flow (figure 9).

Note: Although pulsed aeration systems are developed so far, that reliable bin operation is achieved, we doubt, whether aeration is the adequate measure to promote flow for new installations. This, above all, when considering the complicated venting and dedusting systems, which must be installed to ensure a trouble-free operation of the subsequent feeders.

The flow regime can also be influenced when changing the wall frictional behavior. A UHMW PE lining in a 70 degree sloped bin discharge hopper would in most cases induce mass-flow. Nevertheless, it is not recommended to base the design of new storage bins for pulverized coal on a UHMW PE lining due to PE's low melting point (~ 135 ° C). But a PE lining is accepted to be an effective measure to convert a funnel-flow sequence to mass-flow in an existing bin.

Bin inserts too, influence the flow regime in a bin. By such inserts, the amount of stagnant material in a funnel-flow bin may be reduced considerably (figure 10). Usual shapes are tables or cones which are placed above the outlet. In contrast to these corrective bin inserts Jenike and Johanson propose a cone-in-cone design (figure 10). The internal cone is designed for mass-flow what width of discharge opening and wall slope concern. It was found that the half angle of the outer cone may be twice the half angle of the inner one. Material will flow through both, the inner hopper and the annulus between inner and outer hopper.

Note: The cone-in-cone system offers not only a simple measure to convert pulverized coal bins with a funnel-flow sequence into mass-flow bins, but also is a possibility to design new bins with discharge hoppers of a reduced height.

4.3 Feeder Systems

Nowadays various gravimetric systems are used for feeding pulverized coal to the several burners of a kiln system. The most important feeding systems are the loss-in-weight and the impact flow meter systems.

In the following, not the advantages of before mentioned feeders should be discussed, it should rather be reflected how a feeder system, as simple as possible could look like.

The discharge equipment of a SIMPLEX feeder with its activating paddle wheels and its proportioning screw is a perfect proportioning screw feeder system when fitted directly to the storage bin (figure 11). Particular care should be taken with the design of the proportioning screw which should be expanding, e.g. with decreasing core and increasing pitch in direction of material flow.

For multiple outlet bins several proportioning screws can be arranged in parallel to each other. If the diameter of the screws is selected sufficiently wide, no further activators are needed (figure 12). Again each proportioning screw should be of an expanding design.

The flow rate can be measured by a subsequent impact flow meter or a proportioning rotor scale, which is quite a new development and will be discussed later. The flow rate is controlled by altering the speed of the screw(s). For calibration purposes the bin should be installed on load cells and can be used as a whole as loss-in-weight system.

Live bottom feeders consist of a vibrated frame with a set of blades. Each blade acts as a vibratory feeder. With this type of feeder, discharge problems are prevented as it promotes flow across the entire section of the bin's discharge opening. These feeders are fitted to the storage bin's discharge opening. These feeders are fitted to the storage bins by means of pressure shock resistant flexible sleeves (figure 13). Again the flow rate can be measured by a subsequent impact flow meter or a proportioning rotor scale. The flow rate can be controlled by altering the vibrator amplitude. For calibration purposes the bin should be installed on load cells.

All above mentioned feeder systems not only consist of the discharge and measuring devices, but additionally of a rotary gate which provides for the air lock to the subsequent pneumatic conveyor. At this point, the proportioning rotor scale should be mentioned, where feeding and weighing are integrated in the same device.

The proportioning rotor scale (figure 14), a suspended scale, consists of a rotor (with vertical axis) installed in an explosion-resistant housing. The two suspension heads are arranged in line with the feed-in duct and the delivery line as to prevent that external forces which result from incorrect connections affect the weighing. The measuring pivot is arranged at the opposite.

For the future the proportioning rotor scale seems to be a very competitive feeder.

4.4 How a Modern Bin Feeder System for Pulverized Coal would look like, when Designed for Reliable Operation

(figure 15)

- ◆ The bin would definitely be designed for mass-flow.
- ◆ A cone-in-cone design would be selected for the bin discharge hopper with wall slopes of 65 degree for the external and 77 degree for the internal hopper.
- ◆ Material of construction for both hoppers would be stainless steel plates.
- ◆ The minimum diameter of the circular hopper discharge openings would be at least 1400 mm.
- ◆ Material discharge would be activated by a live bottom feeder.
- ◆ The flow rate would be controlled by a proportioning rotor scale (or a flow meter).

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Table 1 Funnel-Flow versus Mass-Flow

	Funnel - flow	Mass - flow
Bin shape	Compact flat hopper	Slender steep hopper
Flow sequence	First in - Last out	First in - First out
Discharge order	Loading order inversed	As loaded
Silo utilisation	partial	complete
Handling problems		
- no flow	arching piping	arching
- discontinuous flow	erratic flow flushing	—
- formation of materials build-ups on silo walls	possible	—
- segregation	inevitable	counteracted

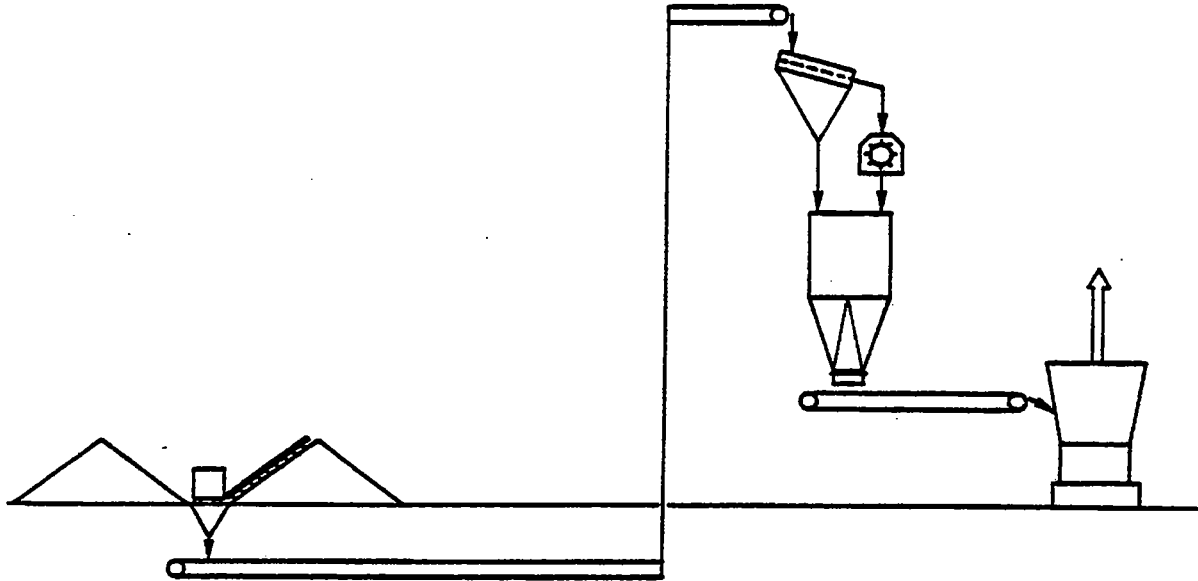
Table 2 Handleability Characteristics of Raw Coal

Moisture content	7 - 15 % H ₂ O
Granulometry:	
- Reference value	50 mm
- Minus 50 mm	95 %
- fraction	50 %
Minus 5 mm fraction	
Material strength	5000 - 7000 Pa
Effective angle of friction	47 - 52 deg
Angle of internal friction	37 - 45 deg
Angles of wall friction:	
- Mild steel	27 - 30 deg
- Stainless steel	28 - 28 deg
- Uhmw polyethylene	22 - 25 deg

Table 3 Design Parameters of Mass-Flow Hoppers for Raw Coal

Type of hopper	Conical	Wedge type
Minimum hopper halfangles:	θ_c	θ_p
- Mild steel	10 - 13 deg	18 - 20 deg
- Stainless steel	12 - 15 deg	20 - 22 deg
- Uhmw polyethylene	15 - 20 deg	22 - 25 deg
Bin discharge opening:		
- Shape	Circular	Slotted
- Min. diameter / width	1200 mm	700 mm
Feeder		
- Min. width	2000 mm	1500 mm

Continuous feed of raw coal bin - Bin capacity: 1 - 3 hours continuous mill operation



A schematic diagram of a cement manufacturing process. On the left, a pile of raw materials is loaded by a front loader into a hopper. The material then moves through a series of rollers and a grinding mill (represented by a gear icon) before entering a large vertical kiln. Inside the kiln, three large rotating drums are shown, each with a hopper at the bottom. The material moves from left to right through these drums. Finally, the finished product is discharged into a storage silo on the right, with an upward arrow indicating the direction of flow.

Figure 2 Outlet Design

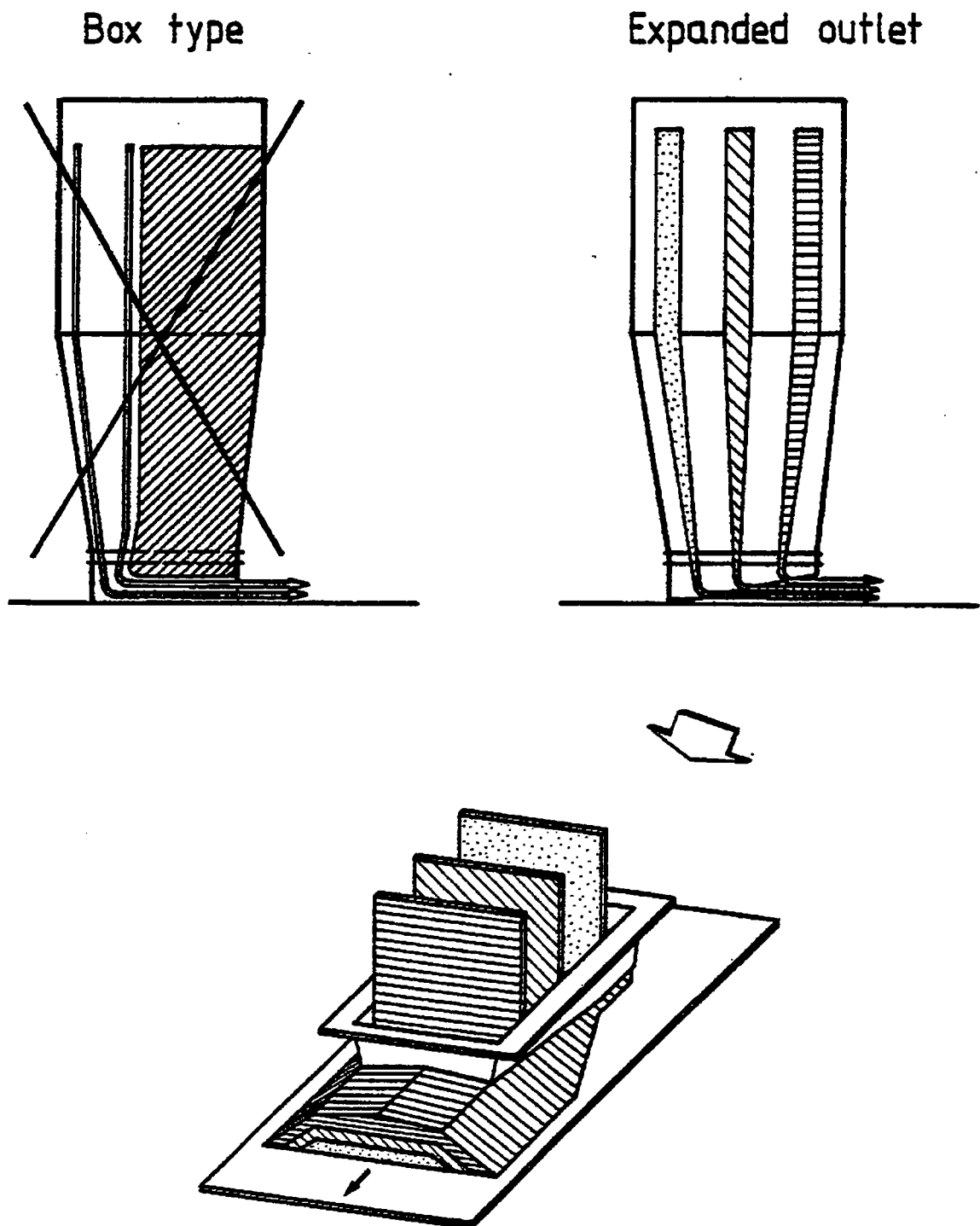
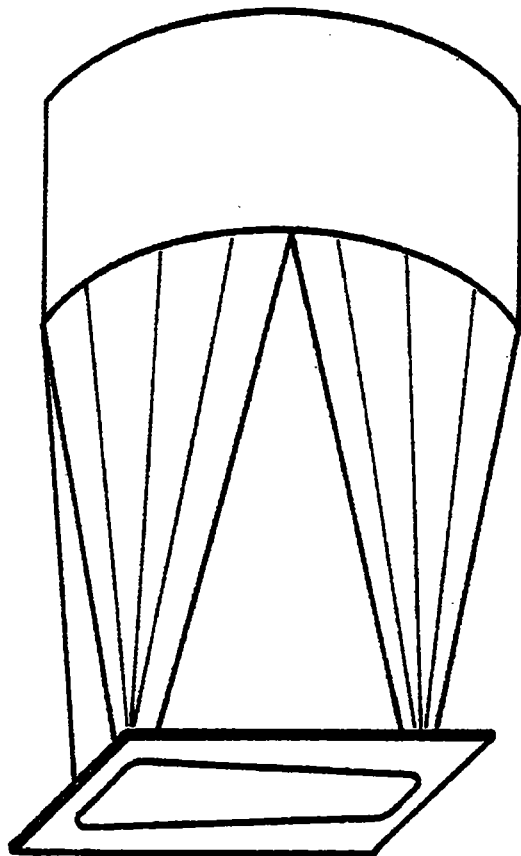
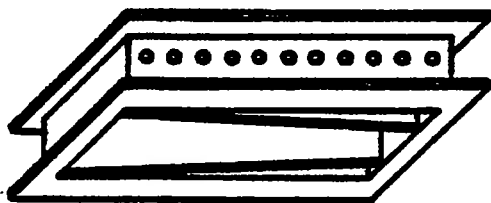


Figure 3 Expanding Bin Outlet

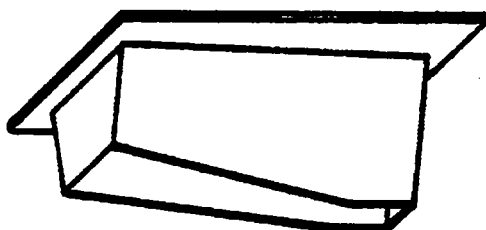


Hopper slopes as
required to meet
mass flow

Expanding discharge
opening with
rounded corners



Pin gate with
guide plates



Interface
expanding
in direction of
material flow



Direction of
material flow

Figure 4 Apron and weigh feeders with expanded outlet

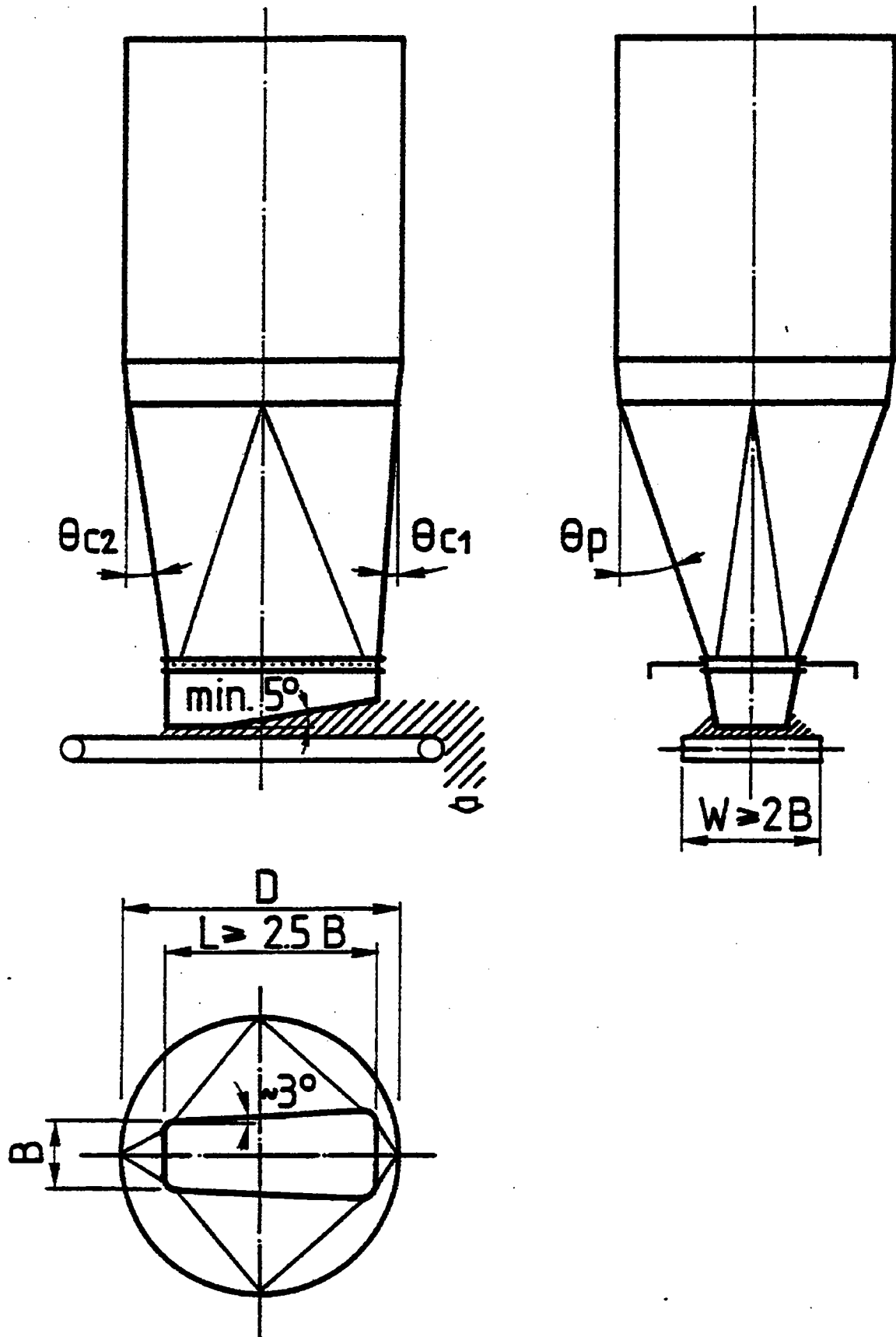


Figure 5 Trough-Chain Feeder with Expanded Outlet

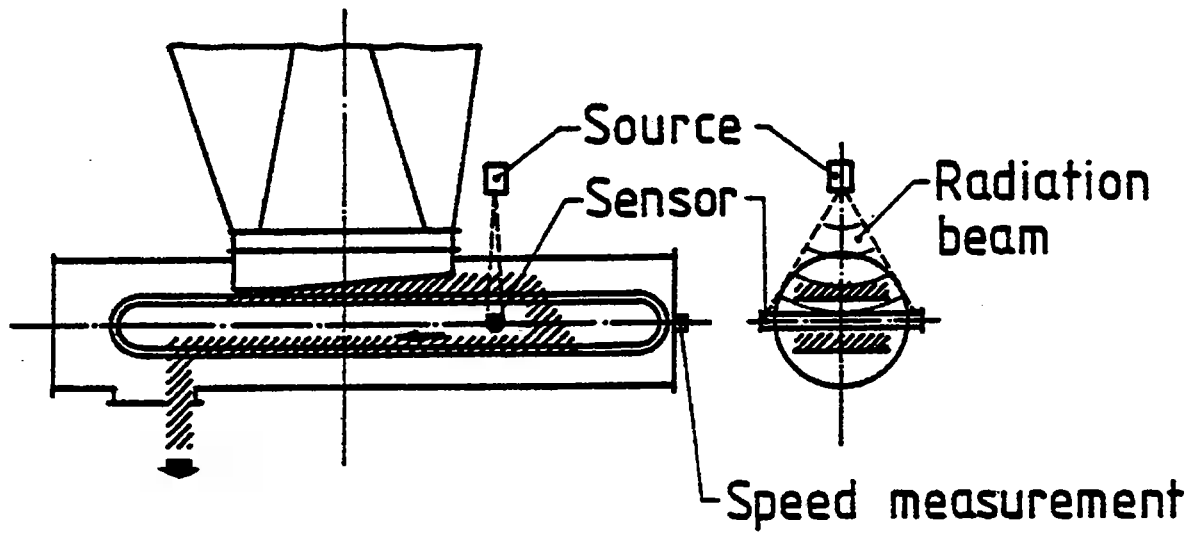


Figure 6 **Table Feeder with Expanding Outlet**

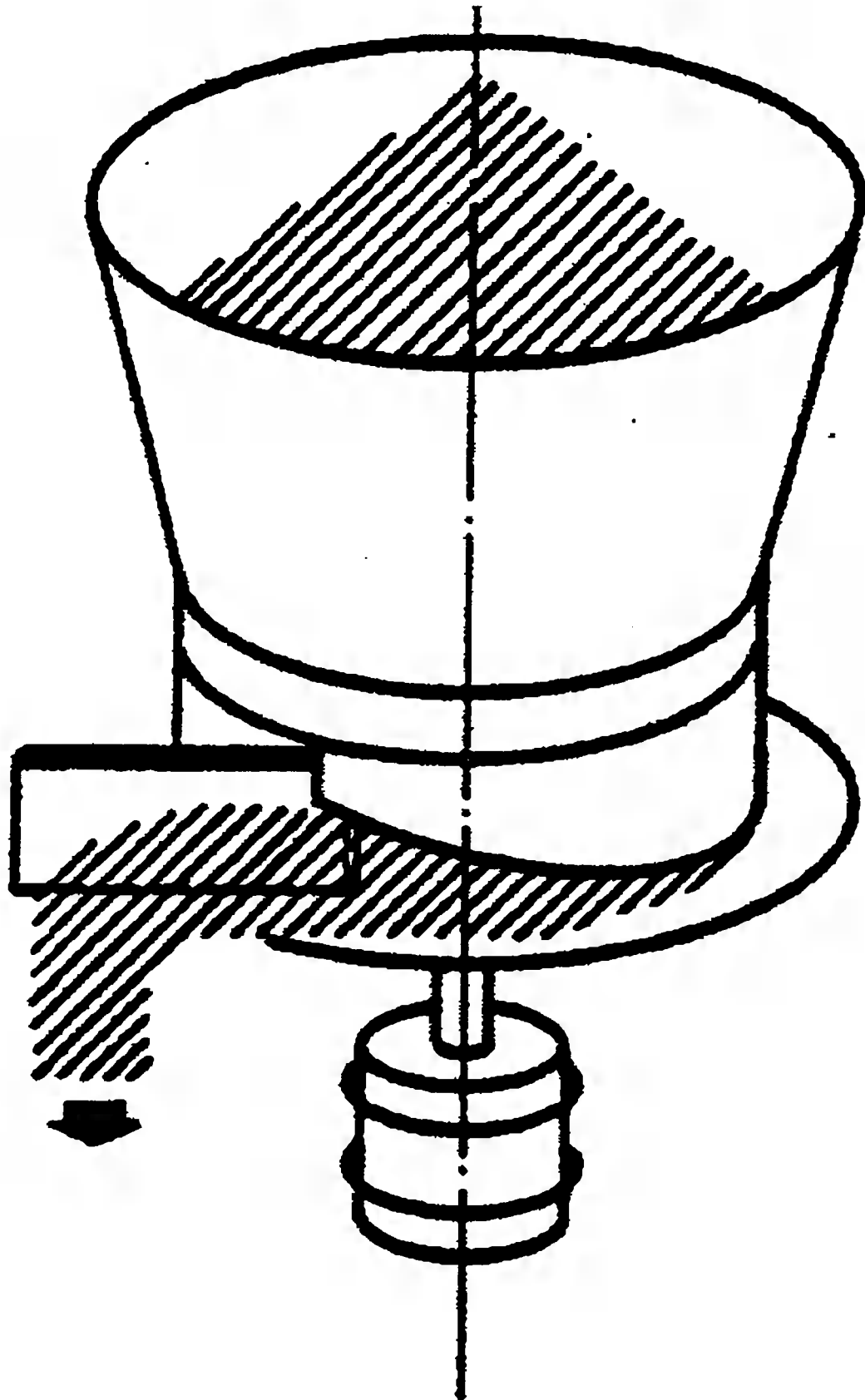


Figure 7 Un-Coaler Activator / Feeder

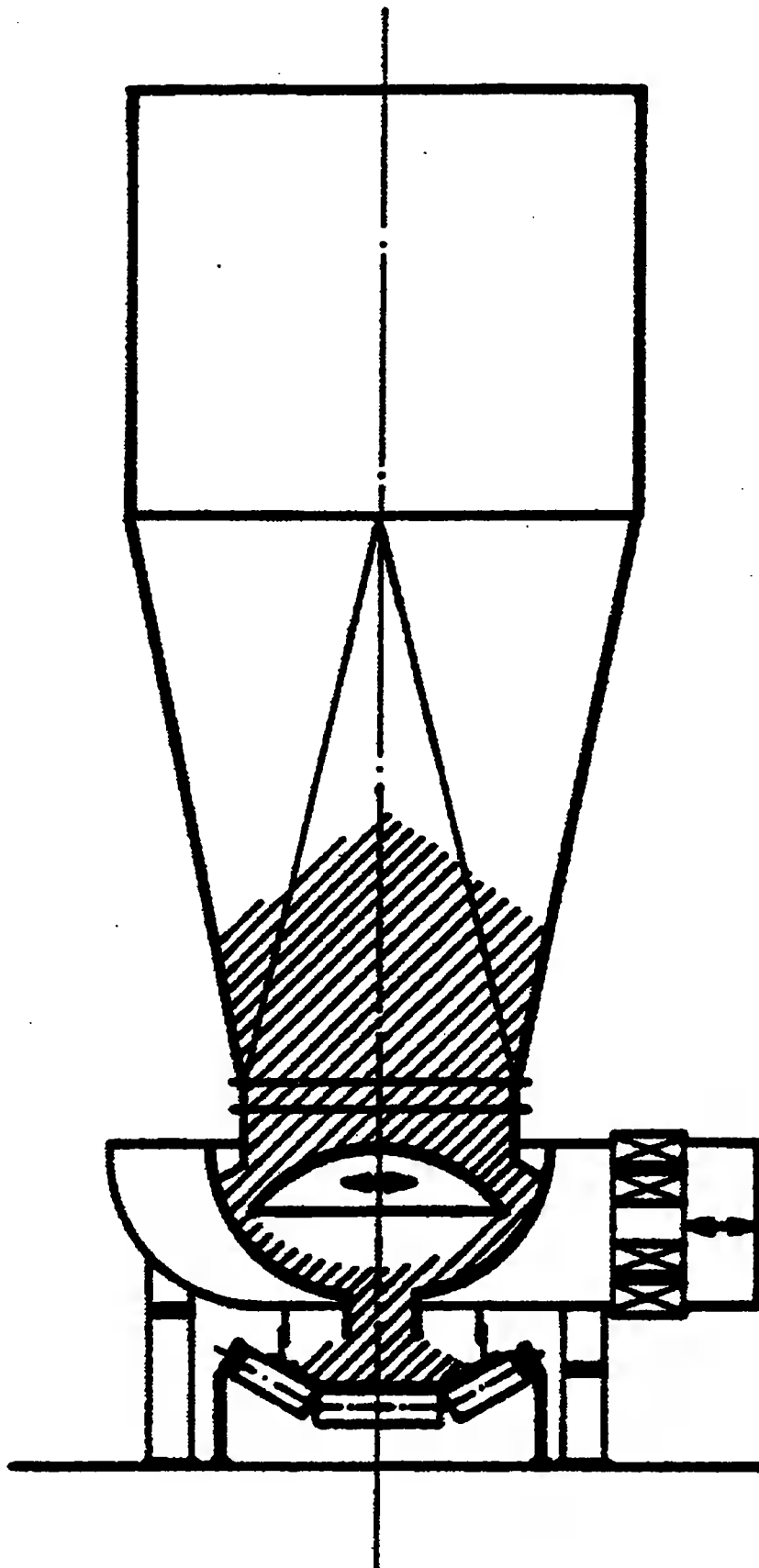


Figure 8 Multiple Bin Discharge for Pulverized Coal

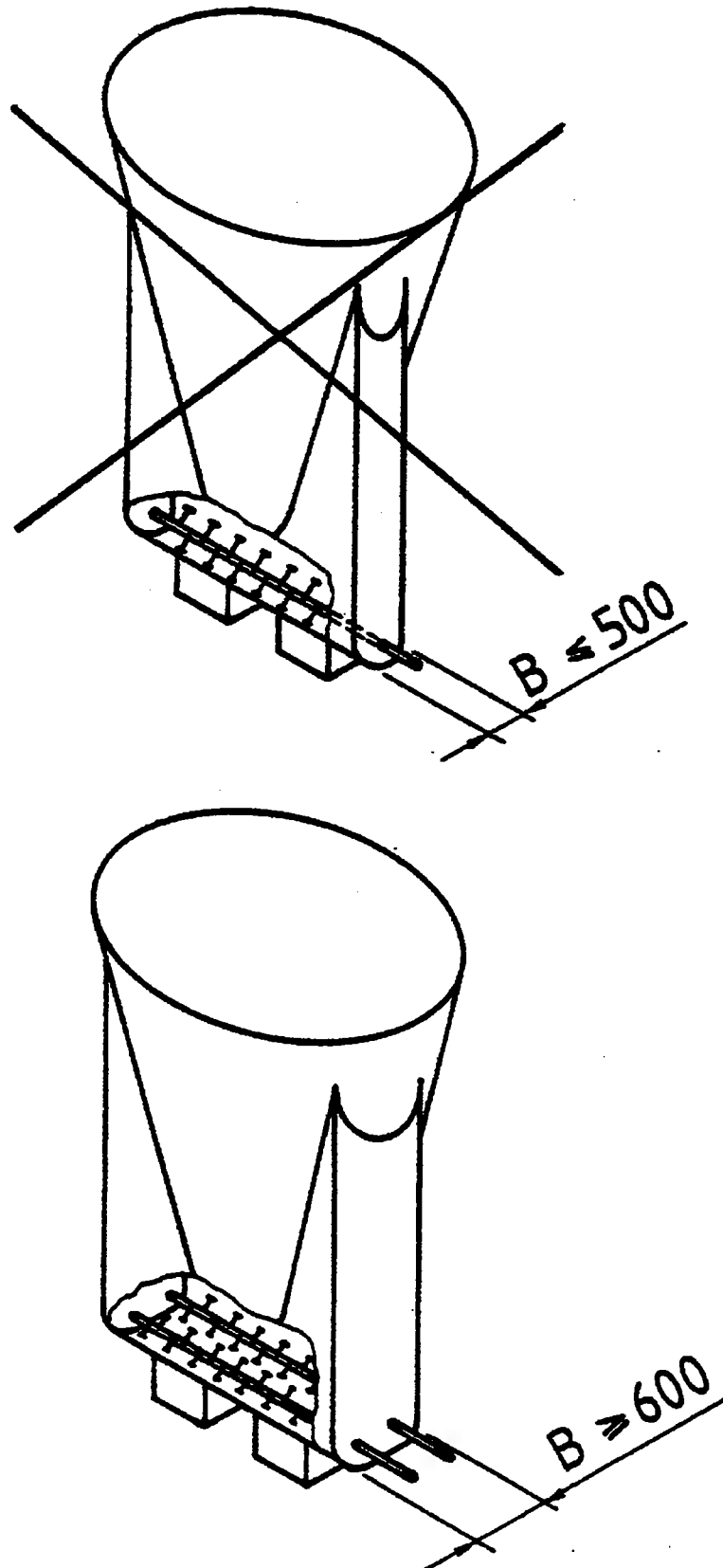


Figure 9 **Flow Promotion by Aeration**

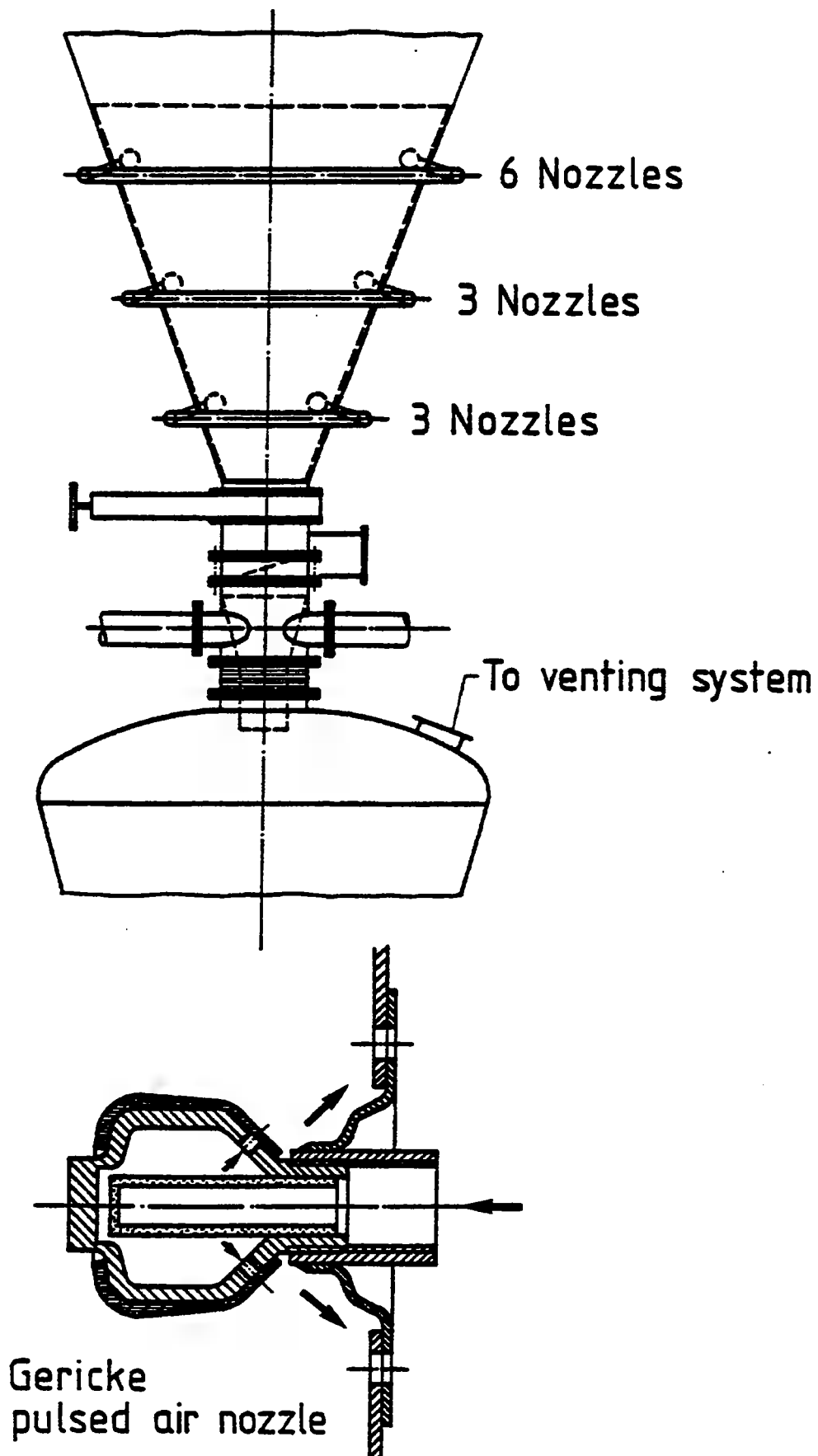


Figure 10 Modification of Flow Pattern by Bin-Inserts

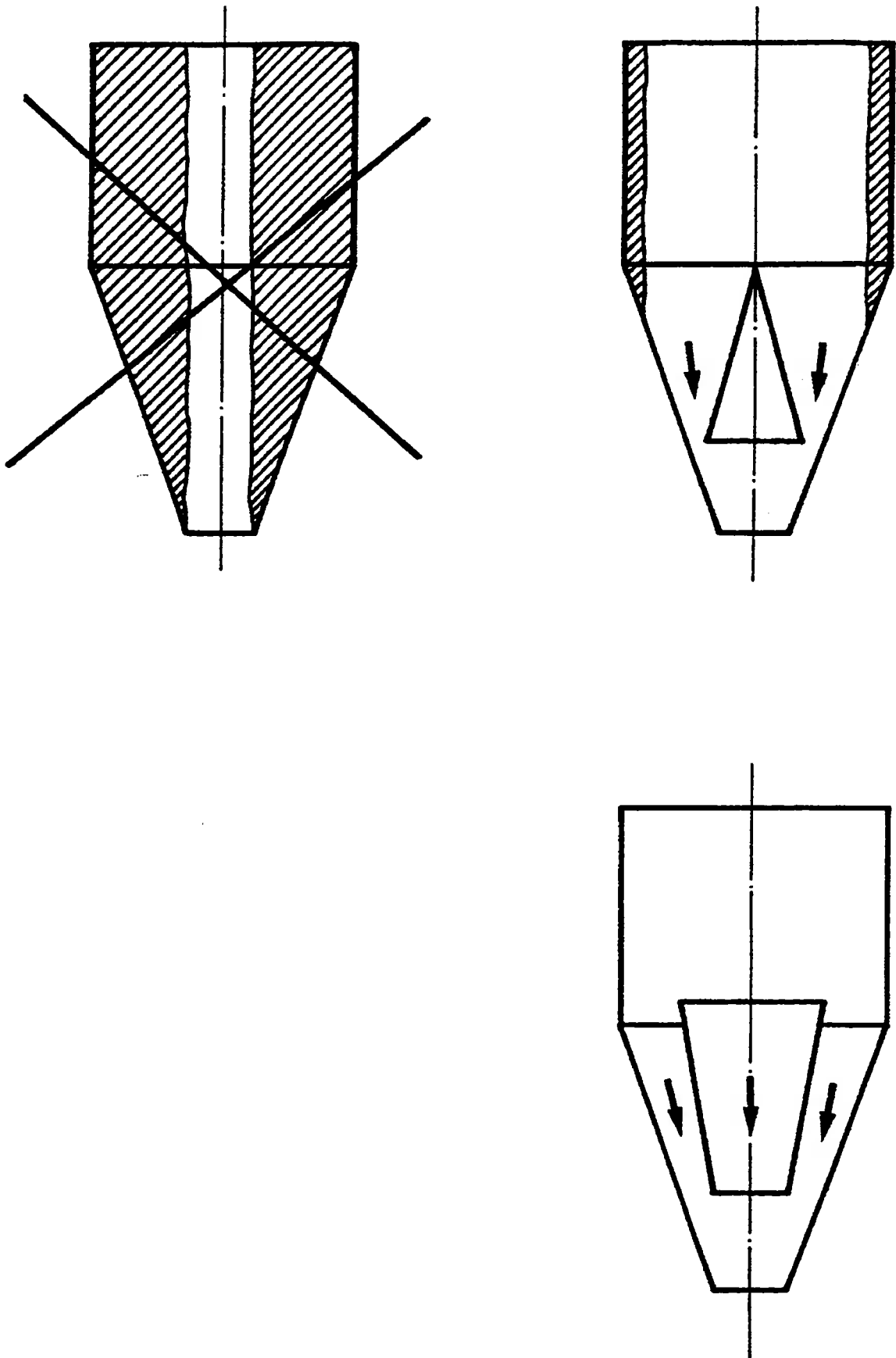


Figure 11 Silo Discharge with Double Paddle and Screw Feeder

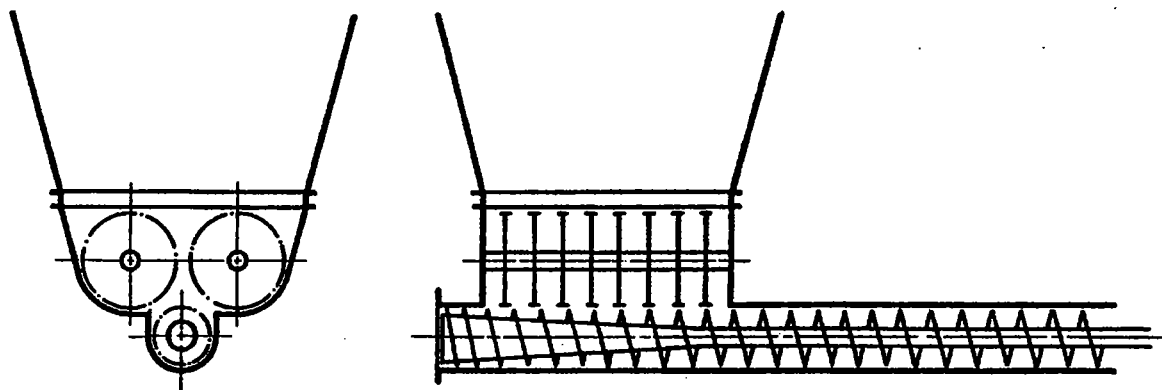


Figure 12 Silo Discharge with Multiple Screw Conveyor (FLS)

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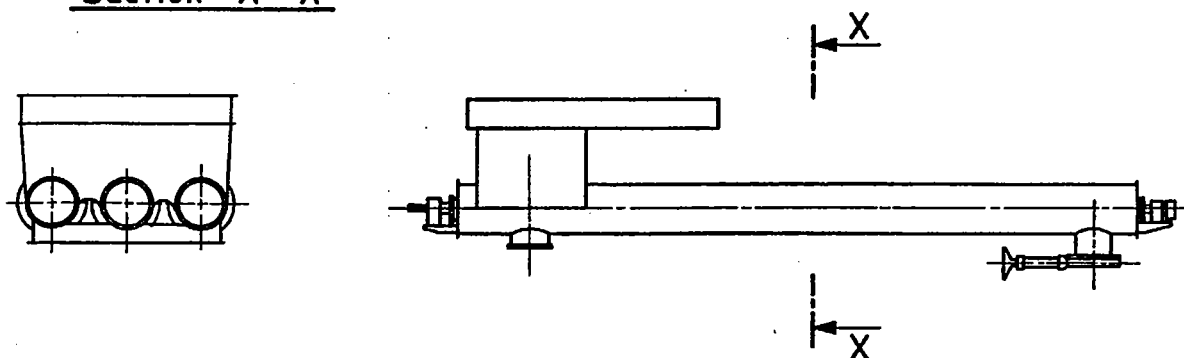


Figure 13 Live Bottom Feeders

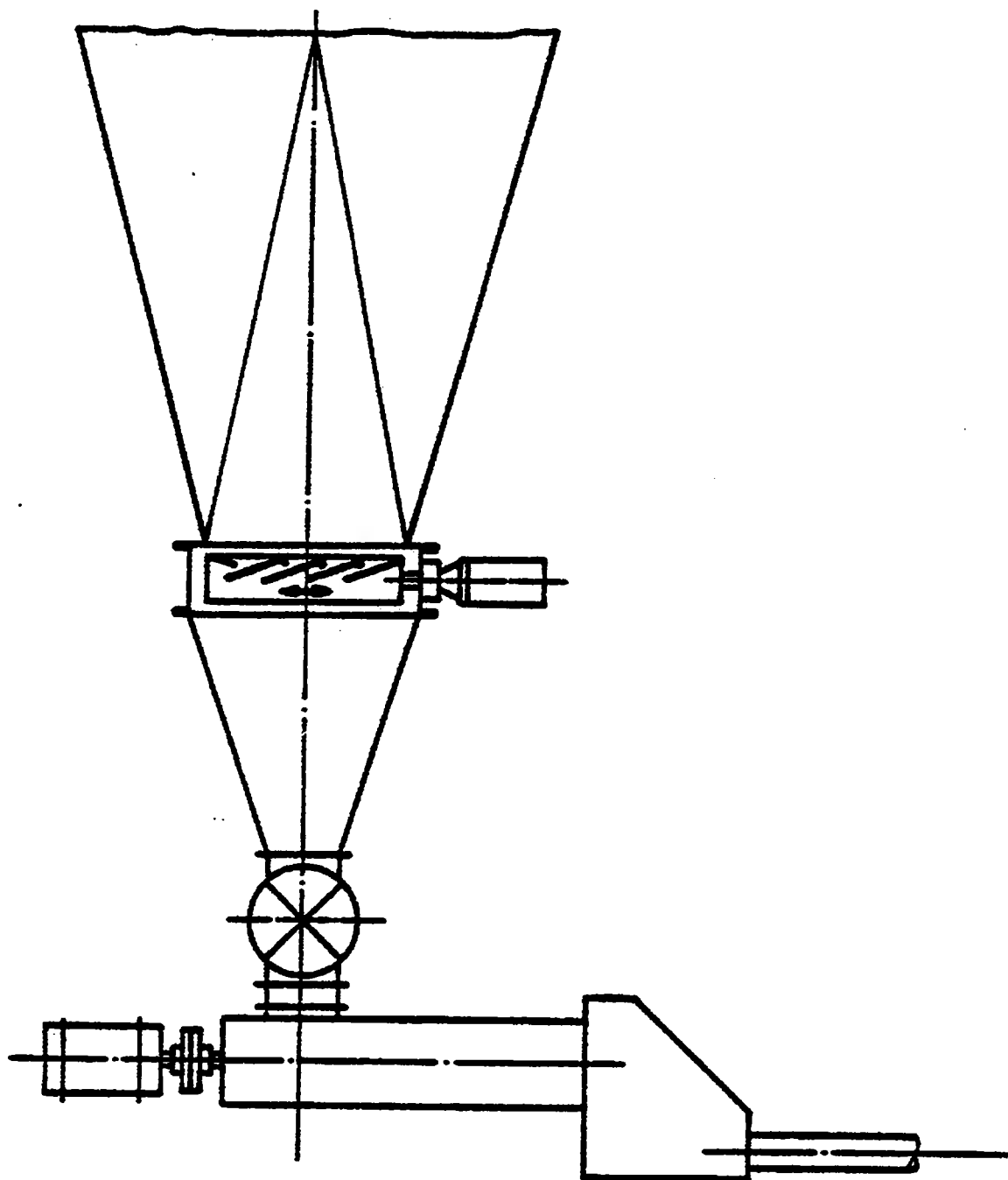


Figure 14 Proportioning Rotor Scale

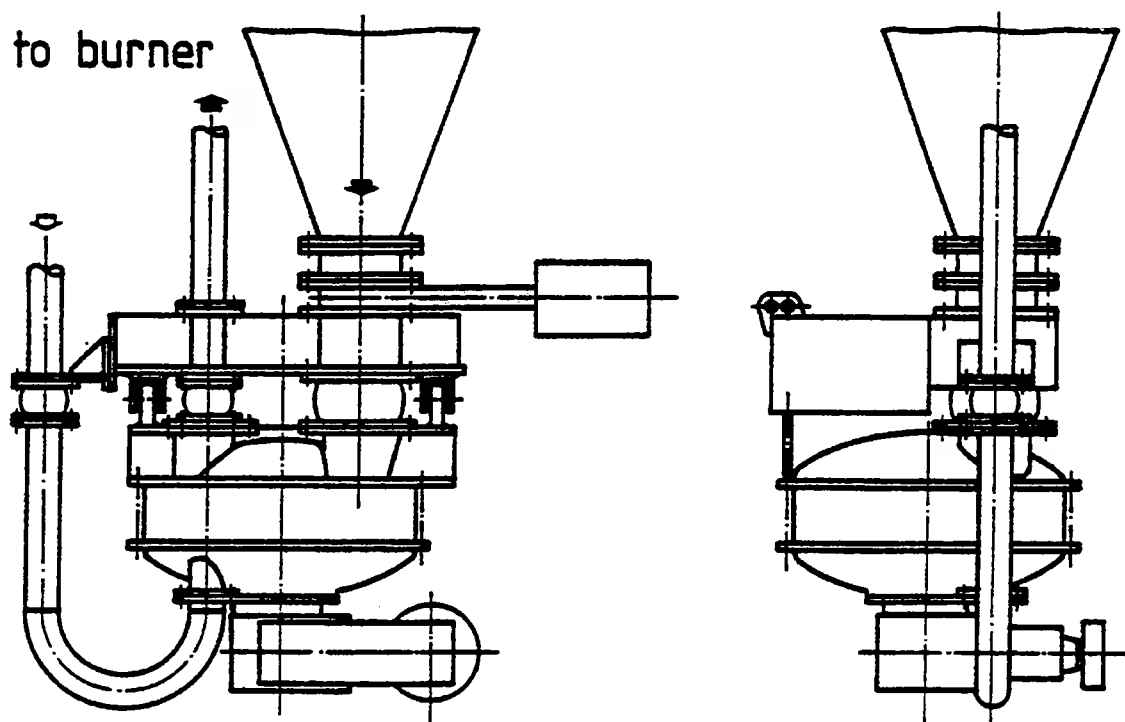
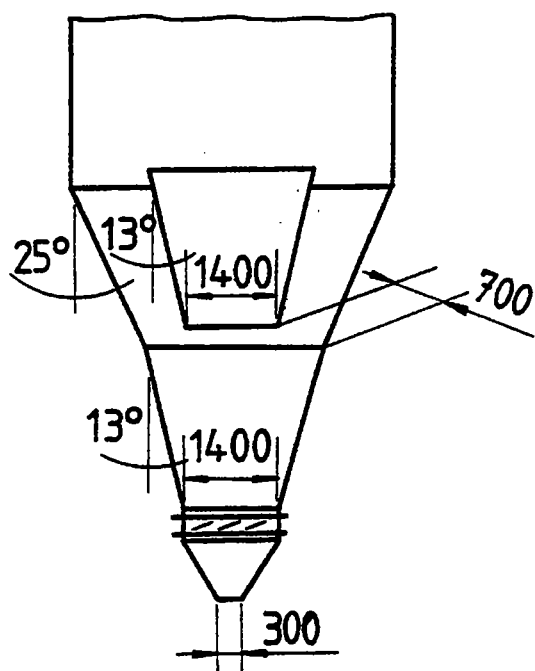


Figure 15 Pulverized Coal Mass-Flow Bin



Cone - in - Cone Design

Live Bottom Feeder

to
 Proportioning Rotor Scale /
 Impact Flow Meter